"Design of concrete structures"

\# **Reinforced Concrete:** When reinforcement is used in cement concrete as a integral part in order to gain an extra strength of the cement concrete, then it is called reinforced concrete or reinforced cement concrete.

\# Why steel is used in reinforced concrete member?

Ans:

i) It is cheap & economical.

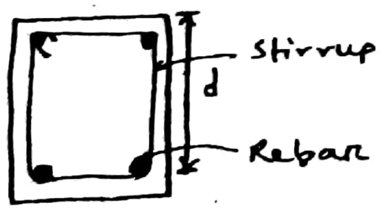
ii) It develops good bond with concrete.

iii) It's thermal expansion co-efficient is near to the concrete.

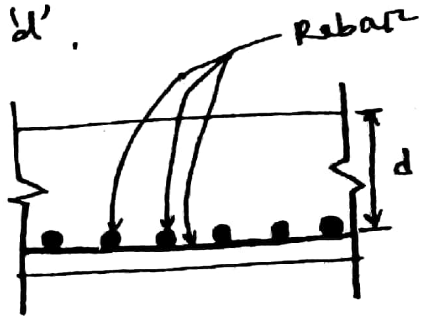
\# What do you mean by M_{10} concrete?

Ans: The letter M refers to the mix 1:3:6 and the number denotes the ultimate compressive strength of 6" cube at 28 days is 10MPa (10×145 = 1450 psi).

\# **Effective depth of a beam:** The effective depth of a beam is the distance from compression face to centroid of tension steel. It is denoted by 'd'.



Beam



For slab

\# **Modular Ratio:** It is the ratio of young's modulus of elasticity of steel ($E_s = 29\times10^6$ psi) to the young's modulus of elasticity of concrete ($E_c = 57000\sqrt{f_c'}$ psi).

$$n = \frac{E_s}{E_c}$$

Fundamental preposition (Assumption) of Reinforced concrete:

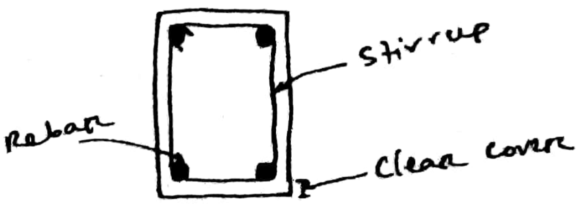
1. plane section remains plane after bending.
2. All forces must be in equilibrium.
3. Strain in reinforcement (ϵ_s) is equal to the strain in surrounding concrete (ϵ_c).
4. Tensile stress of concrete is only a small fraction of it's Compressive strength.
5. Method of elastic analysis is only approximate.
6. Stress is proportional to strain upto elastic limit.

Necessity of reinforcement in concrete beam:

1. Concrete is weak in tension. Steel is provided in the beam to resist the tensile stress.
2. To resist Compression force and reduce the cross-sectional dimension of beam hence weight is reduced.
3. To reduce Long term deflection.
4. To avoid sudden failure.

What is clear cover? Why it is used?

Ans: A clear cover is the distance between the outer face of the stirrup to the finished concrete surface.



For Beam

Because of -

1. to prevent the steel from weathering effect.
2. to prevent the steel from corrosion.
3. to provide thermal insulation.

Component Name	clear cover
Slab	$\geq 0.75''$
Beam	$\geq 1\frac{1}{2}''$
column	$\geq 1\frac{1}{2}''$ (3" for saline zone)
concrete placed on ground	$\geq 2''$
concrete cast on ground	$\geq 3''$

* Difference between WSD & USD Method.

WSD Method	USD Method
① Consider to design at applied load.	① considered to design at factored load.
② It is hight cost design method than USD.	② It is Low cost design method.
③ Modular ratio used for member design.	③ Materials strength is used for member design.
④ stability of structure is less than USD.	④ stability of structure is more than WSD.
⑤ Focuses on stress conditions within the structural member.	⑤ Focuses on strength capacity of the member.

* Define Under reinforced, over reinforced and balanced reinforced section.

Ans: Under reinforced section: if the steel reaches it's yielding before the concrete reaches its ultimate strain.

over reinforced section: when the concrete reaches its ultimate strain before yielding of steel.

Balanced reinforced section: when the concrete reaches its ultimate strain at the same time steel reaches its yielding.

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Difference between reinforced concrete and pre-stressed concrete.

Reinforced Concrete	pre-stressed concrete
① Combines concrete & steel bars by simply putting them together.	① Combines high strength steel with high strength concrete in active manner.
② The entire section of concrete becomes effective.	② Only the portion above NA is effective.
③ High volume of concrete is used.	③ Low volume of concrete is used.

"Beam"

Singly Reinforced Beam: If reinforcements are required to resist tensile force at tensile zone of concrete beam, then the beam is known as singly reinforced beam.

Doubly Reinforced Beam: If the beam is limited by cross-section, then it may happen that the concrete can not develop the compressive force to resist the moment, in such case reinforcement is provided in compression zone. So, beams having reinforcement in both tension & compression zone are termed as doubly reinforced beam.

Why beam is designed as under reinforced?

Ans: The compression failure occurs without warning. For this reason, it is good practice to keep amount of reinforcement sufficiently small so that, it will give adequate warning before failure by gradual yielding.

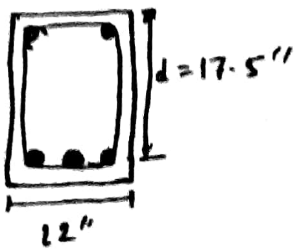
Bar NO	Dia, inch (mm)	Area (in^2)
# 3	3/8" (10)	0·11
# 4	4/8" (12)	0·20
# 5	5/8" (16)	0·31
# 6	6/8" (20)	0·44
# 7	7/8" (22)	0·60
# 8	1' (25)	0·79
# 9	9/8" (28)	1·00
# 10	10/8' (32)	1·27
# 11	11/8" (36)	1·56

Singly Reinforced Beam:

Moment calculation (WSD)

A rectangular beam has a width of 12" and an effective depth to the centroid of the reinforcing steel is 17.5". It is reinforced with three No. of #8 bars in one row. $f_y = 60$ksi, $f'_c = 4$ksi. Find the maximum flexural (Moment) capacity of the beam. Also find out the load capacity.

Soln:



$f_s = 0.4 f_y$; $f_c = 0.45 f'_c$

$= 24$ KSI ; $= 1.8$ KSI

$r = \frac{f_s}{f_c} = 13.33$

$n = \frac{E_s}{E_c} = \frac{29\times10^6}{57000\sqrt{4000}} \simeq 8$

$k = \frac{n}{n+r} = 0.375$

$j = 1 - k/3 = 0.875$

$A_s = 3 * 0.79 = 2.37$ in^2

$M_c = \frac{f_c}{2} jkbd^2$

$= \frac{1.8}{2} \times .875 \times .375 \times 12 \times 17.5^2$

$= 1085.27$ k-in

$= 90.44$ k-ft

$M_T = A_s f_s jd$

$= 2.37 \times 24 \times .875 \times 17.5$

$= 870.97$ k-in $= 72.58$ k-ft.

$\therefore$ Maximum flexural capacity $= 72.58$ k-ft.

Load capacity:

$M = \frac{wl^2}{8}$ | Assume simply supported beam with $l = 25'$

$\Rightarrow w = \frac{8 \times 72.58}{25^2}$

$= 0.93$ k/ft

Ans.

* **For WSD method:**

Steel Ratio, $\rho = \frac{A_s}{bd}$

Balance steel Ratio, $\rho_b = \frac{n}{2r(n+r)}$

i) if $\rho > \rho_b \rightarrow$ concrete reach ultimate strain before steel

ii) if $\rho < \rho_b \rightarrow$ steel reach yielding before concrete.

* **Moment calculation: (USD)**

Nominal moment capacity, $M_n = A_s f_y \left(d - \frac{a}{2}\right)$
$= \rho b d^2 f_y \left(1 - .59 \rho \frac{f_y}{f'_c}\right)$

Ultimate moment capacity, $M_u = \phi M_n \; [\phi = 0.9]$

where, $a = \frac{A_s f_y}{.85 f'_c b}$

Balance steel Ratio, $\rho_b = 0.85 \beta_1 \frac{f'_c}{f_y} * \frac{87000}{87000 + f_y}$

$= 0.85 \beta_1 \frac{f'_c}{f_y} * \frac{0.003}{0.003 + 0.004}$

Maximum steel Ratio, $\rho_{max} = 0.75 \rho_b$

Minimum steel Ratio, $\rho_{min} = 3 * \frac{\sqrt{f'_c}}{f_y} b_w d \geq \frac{200}{f_y} b_w d$

$\rho_{max} > \rho > \rho_{min} \rightarrow$ Singly reinforced beam (tensile steel yields).

Value of β_1:

f'_c (psi) –	4000	5000	6000	7000	8000
β_1 –	0.85	.80	.75	.70	.65

$\beta_1 = 0.85 - 0.05 \frac{f'_c - 4000}{1000}$ [where $f'_c \geq 4000$]

$0.65 \leq \beta \leq 0.85$

* A rectangular beam has width of 12 in, an effective depth to the centroid of the reinforcing steel is 17.5 in. It is reinforced with 4 #9 bar in one row. $f_y = 60$ ksi, $f'_c = 4$ ksi, what is the ultimate moment capacity of the beam?

Soln:

$$\rho = \frac{A_s}{bd} = \frac{4\times 1}{12\times 17.5} = 0.0159$$

$$\rho_b = 0.85\,\beta_1 \frac{f'_c}{f_y} \times \frac{87000}{87000+f_y}$$

$$= 0.85\times 0.85\times \frac{4}{60} \times \frac{87000}{87000+60000} = 0.0285$$

$$\rho_{max} = 0.75\,\rho_b = 0.0214$$

$\rho_{max} > \rho \rightarrow$ singly reinforced beam.

$$M_n = A_s f_y (d - a/2)$$

$$= (4\times 1)\times 60 \left(17.5 - \frac{5.88}{2}\right)$$

$$= 4334.4 \text{ k-in}$$

$$= 361.2 \text{ k-ft.}$$

$$a = \frac{A_s f_y}{.85 f'_c b} = \frac{(4\times 1)\times 60}{.85\times 4\times 12} = 5.88''$$

$$M_u = \phi M_n = 0.9\times 361.2 = 324.18 \text{ k-ft}$$

Ans.

Design of beam and Area of steel (WSD)

* Design a beam and find amount of steel as a simply supported beam having span of 20′ with a uniformly distributed load of 650lb/ft (including self wt). $f_y = 60$ ksi, $f'_c = 3$ ksi.

Soln: Let, $b = 12''$.

$w = 650$ lb/ft, $L = 20$ ft

$$M_{dev} = \frac{wL^2}{8} = \frac{650 \times 20^2}{8} = 32500 \text{ lb-ft.}$$

$f_s = .4 f_y = 24$ ksi

$f_c = .45 f'_c = 1.35$ ksi

$$r = \frac{f_s}{f_c} = 17.78$$

$$n = \frac{E_s}{E_c} = \frac{29 \times 10^6}{57000\sqrt{3000}} \simeq 9$$

$$K = \frac{n}{n+r} = 0.378$$

$$j = 1 - K/3 = 0.874$$

$$M_c = \frac{f_c}{2} jKbd^2$$

$$\Rightarrow d = \sqrt{\frac{2M_c}{f_c jKb}} = \sqrt{\frac{2 \times 32500 \times 12}{1.35 \times 10^3 \times .874 \times .378 \times 12}}$$

$= 12.1'' \simeq 12.5''$

Total depth, $t = 12.1 + 1.5 \simeq 14''$

$$\therefore \text{steel Area, } A_s = \frac{M_T}{f_s jd} = \frac{32500 \times 12}{24 \times 10^3 \times .874 \times 12.5} = 1.49 \text{ in}^2$$

use #8 bar, No. of bar $= \frac{1.49}{.79} \simeq 2$ Nos.

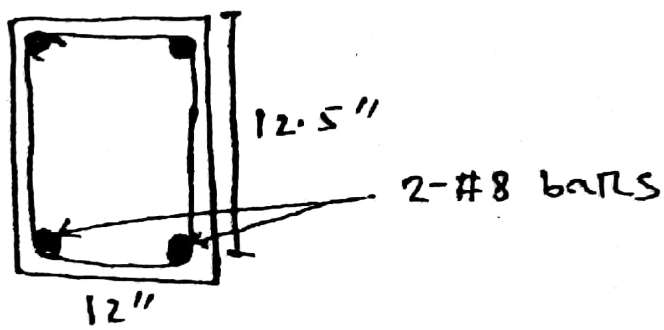


Fig: Reinforcement detailing.

* A rectangular beam carries a uniformly distributed live load of 680 lb/ft & supports the dead load of a wall weighing 380 lb/ft. in addition to its self weight on a simple span of 24'. Design the beam for flexure using $f_y = 50ksi$, $f'_c = 3ksi$.

Soln: Let, $b = 10''$

$f_s = .4 f_y = 20 ksi$

$f_c = .45 f'_c = 1.35 ksi$

$r = \frac{f_s}{f_c} = 14.81$

$n = \frac{E_s}{E_c} \simeq 9$

$k = \frac{n}{n+r} = 0.378$

$j = 1 - k/3 = 0.874$

Load without self weight,

$w = (680 + 380)$
$= 1060$ lb/ft.

$M = \frac{wl^2}{8} = 76320$ lb-ft.

now, $M = M_c = \frac{f_c}{2} jk b d^2$

$\Rightarrow d = \sqrt{\frac{2 \times 76320 \times 12}{1350 \times .874 \times .378 \times 10}}$
$= 18.5''$

$\therefore$ Total thickness, $t = 18.5 + 1.5 = 20''$

$\therefore$ self wt of beam $= \frac{10 \times 20}{144} \times 150 = 208$ lb/ft.

$\therefore$ Total load, $w = 1060 + 208 = 1268$ lb/ft.

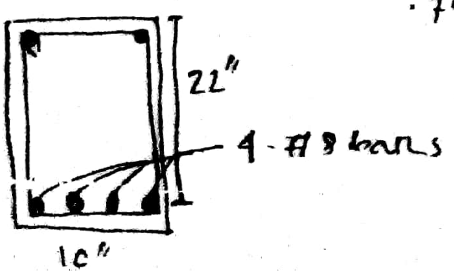
$M = \frac{wl^2}{8} = 91296$ lb-ft.

$\therefore d = \sqrt{\frac{2 \times 91296 \times 12}{1350 \times .874 \times .378 \times 10}} = 22'' > 20''$ Not ok

$\therefore$ Total thickness, $t = 22 + 1.5 \simeq 24''$

$\therefore A_s = \frac{M}{f_s j d} = \frac{91296 \times 12}{20000 \times .874 \times 22} = 2.85 \, in^2$

use #8 bar. No. of bar $= \frac{2.85}{.79} \simeq 4$ No.



* Design the steel when acting moment of a simply supported structure are 1600 K-in. Effective depth 16.5", width = 10", $f'_c = 4000$ psi, $f_y = 60000$ psi.

Sol^n:

$M = A_s f_s j d$

$\Rightarrow A_s = \dfrac{M}{f_s j d}$

$= \dfrac{1600}{24 \times .874 \times 16.5}$

$= 4.62 \text{ in}^2$

$f_s = .4 f_y = 24$ ksi

$f_c = .45 f'_c = 1.8$ ksi

$r = \dfrac{f_s}{f_c} = 13.33$.

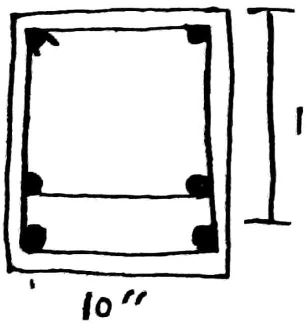
$n = \dfrac{E_s}{E_c} \simeq 8$

$k = \dfrac{n}{n+r} = 0.376$

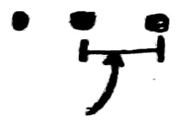
$j = 1 - k/3 = 0.874$

use # 10 bar.

No. of bar $= \dfrac{4.62}{1.27} \simeq 4$ Nos.



Note:



= max^m size of aggregate (3/4) + 1.5 + dia of bar.

* Design of Beam: (USD)

* Find the cross-section and area of steel required for a simply supported rectangular beam with a 20ft span subjected to a calculated dead load of 1.5k/ft and live load of 2k/ft. $f'_c = 5ksi$, $f_y = 60ksi$

Soln: Let, $b = 12''$

$W_u = 1.2DL + 1.6L = 1.2 \times 1.5 + 1.6 \times 2$

$= 5k/ft.$

$$M_u = \frac{W_u l^2}{8} = \frac{5 \times 20^2}{8} = 250\ k\text{-}ft.$$

β_1 for 5000psi $= 0.80$

$$\therefore \rho_b = 0.85 \beta_1 \frac{f'_c}{f_y} \frac{.003}{.003 + .004} = 0.0243$$

$\rho_{max} = .75 \rho_b = 0.0182$

$$M_u = \phi M_n = 0.9 \rho f_y b d^2 \left(1 - .59 \rho \frac{f_y}{f'_c}\right)$$

$$\Rightarrow 250 \times 12 = .9 \times .0182 \times 60 \times 12 \times d^2 \left(1 - .59 \times .0182 \times \frac{60}{5}\right)$$

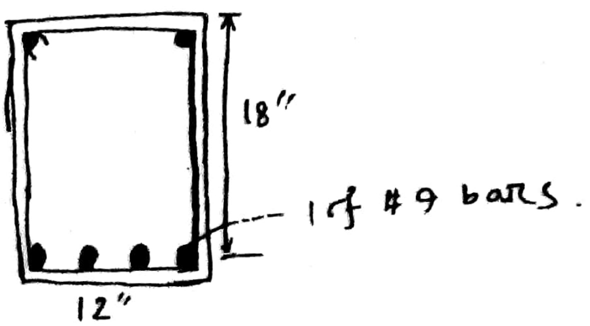
$\Rightarrow d = 18''$

$\therefore$ Total thickness, $t = 18 + 2.5'' = 20.5''$

$\therefore A_s = \rho_{max} b d = .0182 \times 12 \times 18 = 3.93\ in^2$

provide #9 bar.

$$\text{No of bar} = \frac{3.93}{1.00} \simeq 4\ nos.$$



Another solution: let, $b = 12''$, $h = 20''$

$M_u = 250$ k-ft, $\rho_b = 0.0243$, $\rho_{max} = 0.0182$

$\therefore A_s = \rho_{max} b d$

$= .0182 \times 12 \times 17.5$

$= 3.82 \text{ in}^2$

$d = 20'' - 2.5''$

$= 17.5''$

$a = \frac{A_s f_y}{.85 f'_c b}$

$= \frac{3.82 \times 60}{.85 \times 5 \times 12}$

$= 4.49''$

$M_{max} = \phi A_s f_y (d - a/2)$

$= 0.9 \times 3.82 \times 60 \left(17.5 - \frac{4.49}{2}\right)$

$= 3146.8$ K-in

$= 262.23$ K-ft

$M_{max} > M_u \rightarrow$ singly reinforced beam.

$A_s = \frac{M_u \,(250 \times 12)}{\phi f_y (d - a/2)}$

$a = \frac{A_s f_y}{.85 f'_c b}$

a	A_s	a
1	3.27	3.84
3.84	3.56	4.19
4.19	3.61	4.25
4.25	3.61	4.25

$\therefore A_s = 3.61 \text{ in}^2$

use #9 bar,

No. of bar $= \frac{3.61}{1} \simeq 4$ Nos

Ans.

* Find out the amount of steel required, when ultimate moment capacity 1600 k-in. Effective depth = 17" and width = 10", $f'_c = 4$ ksi, $f_y = 60$ ksi.

Soln:

$$A_s = \frac{M}{\phi f_y (d - a/2)} \quad ; \quad a = \frac{A_s f_y}{.85 f'_c b}$$

a	As	a
1	1.796	3.17
3.17	1.92	3.38
3.38	1.93	3.40
3.40	1.93	3.40

$\therefore A_s = 1.93 \text{ in}^2$

use # 8 bar,

$$\text{no. of bar} = \frac{1.93}{.79}$$

$\simeq 3$ Nos.

Ans.

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Doubly Reinforced Beam:

* Moment Calculation: (WSD)

* Find out the flexural (Moment) capacity or load capacity of a rectangular beam which contains 5-#6 bars at tension face and 2-#5 bars at compression face. The span length of the simply supported beam is 18'. Effective depth = 17.5", b = 10", f'_c = 3 ksi, f_y = 60 ksi.

<u>sol^n:</u>

$f_s = .4 f_y = 24$ ksi

$f_c = .45 f'_c = 1.35$ ksi

$r = \frac{f_s}{f_c} = 17.78$

$n = \frac{E_s}{E_c} \approx 9$

$k = \frac{n}{n+r} = 0.336$

$j = 1 - k/3 = 0.888$

$M_1 = f_c/2 \, jkbd^2$

$= \frac{1.35}{2} \times .888 \times .336 \times 10 \times 17.5^2$

$= 617$ k-in

$\therefore As_1 = \frac{M_1}{f_s jd}$

$= \frac{617}{24 \times .888 \times 17.5}$

$= 1.65$ in^2

$\therefore As_2 = (5 \times .44) - 1.65 = 0.55$ in^2

<u>Tension zone moment:</u>

let, $d' = 2"$

$M_2 = As_2 f_s (d - d')$

$= .55 \times 24 (17.5 - 2)$

$= 204.6$ k-in.

Again,

$A'_s = 2 \times .31 = 0.62$ in^2

$f'_s = 2 f_s \frac{k - \frac{d'}{d}}{1 - k} = 2 \times 24 \times \frac{.336 - \frac{2}{17.5}}{1 - .336}$

$= 16.02$ ksi < 24 ksi

<u>OK</u>

<u>compression zone moment:</u>

$M_2 = A'_s f'_s (d - d')$

$= .62 \times 16.02 (17.5 - 2)$

$= 153.95$ k-in

As moment in comp. zone is less than the moment in tension zone. So the beam is over reinforced condition.

$\therefore$ Max^m moment carrying capacity

$= 617 + 153.95$

$= 770.95 \text{ k-in}$ Ans.

Load carrying capacity:

$$M = \frac{wl^2}{8}$$

$$\Rightarrow w = \frac{8 \times 770.95}{18^2 \times 12} = 1.586 \text{ K/ft}$$ Ans.

* Moment calculation (USD)

* A rectangular beam has a width of 12" and an effective depth to the centroid of the tension reinforcement of 24". The tension reinforcement consists of 6-#10 bars in two rows. Compression reinforcement consisting of 2-#8 bars is placed 2.5 in from the compression face of the beam. $f_y = 60{,}000$ psi, $f_c' = 5000$ psi. What is the moment capacity of the beam?

Sol^n: $A_s = 6 \times 1.27 = 7.62 \text{ in}^2$

$A_s' = 2 \times 0.79 = 1.58 \text{ in}^2$

$$\rho = \frac{A_s}{bd} = \frac{7.62}{12 \times 24} = 0.0265$$

$$\rho' = \frac{A_s'}{bd} = \frac{1.58}{12 \times 24} = 0.0055$$

check:

$$\rho_b = 0.85 \beta_1 \frac{f_c'}{f_y} \frac{87000}{87000 + 60000}$$

$$= 0.85 \times 0.80 \times \frac{5}{60} \times \frac{87000}{87000 + 60000} = 0.0335$$

$\rho_{max} = .75 \rho_b = 0.025$

$\therefore \rho > \rho_{max} \rightarrow$ Doubly reinforced beam

$M_1 = \varphi A_s' f_y (d - d')$

$= .9 \times 1.58 \times 60 (24 - 2.5) = 1834.38$ k-in

$M_2 = \varphi (A_s - A_s') f_y (d - a/2)$

$= .9 (7.62 - 1.58) \times 60 \times (24 - \frac{7.11}{2})$

$= 6668.34$ k-in

$a = \frac{(A_s - A_s') f_y}{.85 f'_c b}$

$= \frac{(7.62 - 1.58) \times 60}{.85 \times 5 \times 12}$

$= 7.11''$

$\therefore M_u = M_1 + M_2$

$= 1834.38 + 6668.34$

$= 8503$ k-in **Ans.**

Design of Beam (WSD)

* A rectangular beam of 15′ simple span carries a UDL of 2600 lb/ft (excluding self weight). Calculate the amount of steel if $f_y = 60$ ksi, $f'_c = 4$ ksi.

Soln: Let, size of Beam $= 10'' \times 18''$

self wt $= \frac{10 \times 18}{144} \times 150$

$= 187.5$ lb/ft.

$\therefore$ total UDL $= 2600 + 187.5$

$= 2787.5$ lb/ft

$M_{dev} = \frac{wl^2}{8} = \frac{2787.5 \times 15^2}{8}$

$= 78398.4$ lb-ft.

$f_s = .4 f_y = 24$ ksi

$f_c = .45 f'_c = 1.8$ ksi

$r = \frac{f_s}{f_c} = 13.33$

$n = \frac{E_s}{E_c} \simeq 8$

$k = \frac{n}{n + r} = 0.375$

$j = 1 - k/3 = 0.875$

$d = 18 - 2.5''$; $d' = 2.5''$

$= 15.5''$

$M = \frac{f_c}{2} j k b d^2$

$= \frac{1800}{2} \times .875 \times .375 \times 10 \times 15.5^2$

$= 709488$ lb-in $= 59124$ lb-ft.

$M_{dev} > M \rightarrow$ Doubly Reinforced beam.

$\therefore M_1 = 59124$ lb-ft

$M_2 = 78398.4 - 59124$

$= 19274.4$ lb-ft.

For tension zone:

$$A_{s1} = \frac{M_1}{f_s j d} = \frac{59124 \times 12}{24000 \times .875 \times 15.5} = 2.18 \text{ in}^2$$

$$A_{s2} = \frac{M_2}{f_s(d-d')} = \frac{19274.4 \times 12}{24000(15.5-2.5)} = 0.74 \text{ in}^2$$

Total tensile steel $= 2.18 + .74$

$= 2.92 \text{ in}^2$

use #9 bar.

No. of bar $= \frac{2.92}{1} \simeq 3$ Nos.

For compression zone:

$$f'_s = 2f_s \frac{k - \frac{d'}{d}}{1-k} = 2 \times 24 \times \frac{.375 - \frac{2.5}{15.5}}{1 - .375}$$

$= 16.4$ ksi $< f_s$ OK

$$A_s' = \frac{M_2}{f'_s(d-d')} = \frac{19274.4 \times 12}{16400 \times (15.5 - 2.5)}$$

$= 0.59 \text{ in}^2$

use # 5 bar.

No. of bar $= \frac{0.59}{0.31} \simeq 2$ Nos.

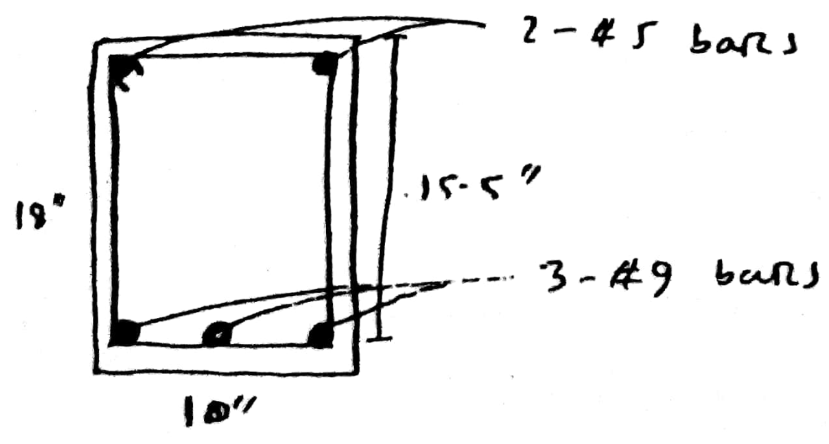

Fig: X-section.

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Design of Beam: (USD)

A rectangular beam is to carry a service load of 2 K/ft & dead load of 1.35 K/ft. The beam is simply supported with a section of 10" x22" and span length of 32'. Design the beam when $f_c' = 4$ ksi & $f_y = 60$ ksi.

Soln: $b = 10''$, $t = 22''$, $d = 22 - 4 = 18''$

$$\text{Total DL} = 1.35 + \frac{10 \times 22}{144 \times 1000} \times 150 = 1.579 \text{ K/ft}$$

$$LL = 2 \text{ K/ft}.$$

Factored load, $W_u = 1.2\,DL + 1.6\,LL$

$$= 5.095 \text{ K/ft}.$$

$$M = \frac{W_u l^2}{8} = \frac{5.095 \times 32^2}{8} = 652.16 \text{ K-ft}.$$

$$\rho_b = 0.85 \beta_1 \frac{f_c'}{f_y} \frac{87000}{87000 + f_y} \qquad [\beta_1 = 0.85]$$

$$= 0.0285$$

$$\rho_{max} = 0.75 \rho_b = 0.0214$$

$$A_s = \rho_{max} b d = 0.0214 \times 10 \times 18 = 3.85 \text{ in}^2$$

$$a = \frac{A_s f_y}{0.85 f_c' b} = \frac{3.85 \times 60}{.85 \times 4 \times 10} = 6.794 \text{ inch}.$$

$$\therefore M_u = \varphi A_s f_y (d - a/2)$$

$$= 0.9 \times 3.85 \times 60 \left(18 - \frac{6.794}{2}\right)$$

$$= 3035.96 \text{ K-in} = 253 \text{ K-ft}.$$

$M > M_u \rightarrow$ Doubly reinforced Beam. $\rightarrow$ (Singly or Doubly check - ~~???~~)

$$M_1 = 253 \text{ K-ft}.$$

$$M_2 = M - M_1 = 652.16 - 253 = 399.16 \text{ K-ft}.$$

$$A_s' = \frac{M_2}{\varphi f_y (d - d')} = \frac{399.16 \times 12}{.9 \times 60 (18 - 3'')} \qquad [d' = 3'']$$

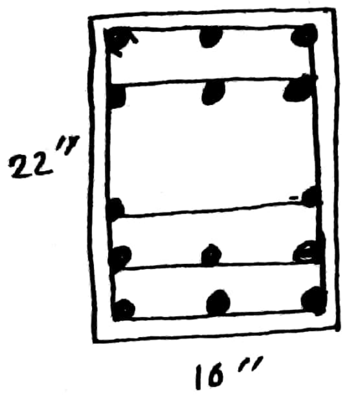
$$= 5.91 \text{ in}^2$$

Tension zone steel = 3.85 + 5.91 = 9.76 in^2

. use #10 bar, No. of bar = $\frac{9.76}{1.27} \simeq 8$ Nos.

Compression zone steel = 5.91 in^2

use #9 bar, No. of bar = $\frac{5.91}{1} \simeq 6$ Nos.



check cg:

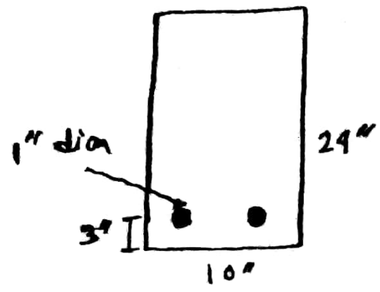
$$\bar{x} = \frac{3\left(1+\frac{1.27}{2}\right) + 3\left(1+1.2+\frac{1.27}{2}+1.27\right) + 2\left(1+1.27+1.2+1.27+1.2+\frac{1.27}{2}\right)}{8}$$

$= 3.7'' < 4''$

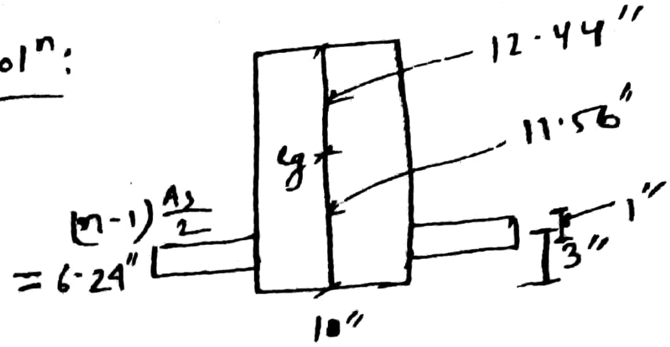
ok

Stress calculation:

A rectangular beam (10" x 24") carries a moment of 45 k-ft. Find out the stress (i) at extreme fiber of concrete beam (ii) at steel. Take n = 9



Soln:



$A_s = 2 \times \frac{\pi}{4} \times 1^2$

$= 1.56\ in^2$

$f_c = \frac{Mc}{I}$

$= \frac{(45 \times 1000 \times 12) \times 12.44}{12481.96}$

$= 538.18\ psi$

$f_s = \frac{45 \times 1000 \times 12 \times (11.56 - 3)}{12481.96}$

$= 370.33\ psi$

Ans.

$\bar{y} = \frac{24 \times 10 \times 12 + (6.24 \times 1 \times 3) \times 2}{24 \times 10 + 6.24 \times 1 \times 2}$

$= 11.56\ in$

$I = \frac{10 \times 24^3}{12} + \left\{24 \times 10 \times (12 - 11.56)^2\right\}$

$+ \left\{\frac{6.24 \times 1^3}{12} + 6.24 \times 1 \times (11.56 - 3)^2\right\} \times 2$

$= 12481.96\ in^4$

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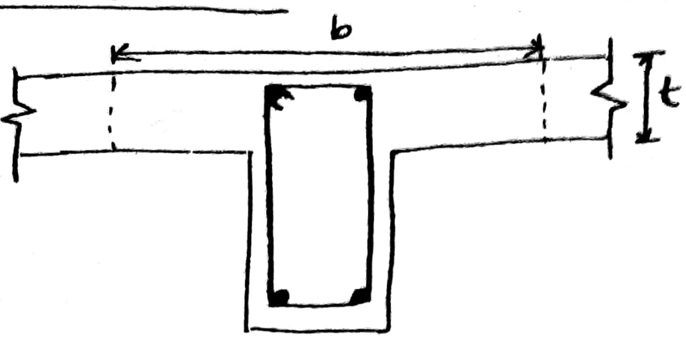
T-Beam: The section of the beam having greater width at the top in comparison to the width below neutral axis is known as T-beam.

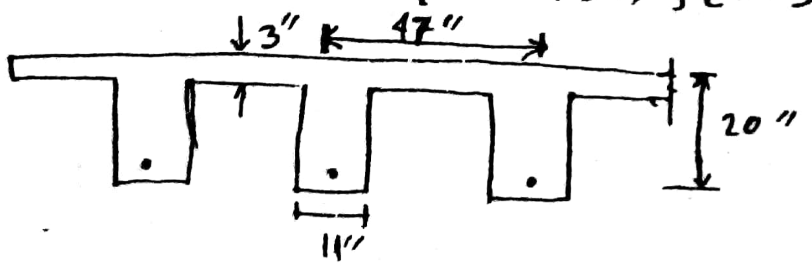
Effective Flange width:



1. Effective width shall not exceed one-fourth of span length, $b \leq L/4$
2. $b \leq 16t + b_w$
3. c/c distance of the beam.

→ accept the smallest one.

* A floor system consists of a 3" concrete slab by span continuous T-beam which carries 2 K/ft dead load and 2.3 K/ft live load. $b_w = 11$ inch, $d = 20''$, c/c spacing of beam = 47". What tensile steel area is required at midspan. ~~to resist~~ $f_y = 60$ ksi, $f'_c = 3$ ksi.



Sol^n: <u>Effective flange width:</u>

1. $b = 16t + b_w = 16 \times 3 + 11 = 59''$
2. $b = \frac{L}{4} = \frac{24 \times 12}{4} = 72''$
3. $b = 47''$

$\therefore b = 47''$

let's take, $a = t = 3''$

$\therefore A_s = \dfrac{M}{\phi f_y (d - a/2)}$

$= \dfrac{437.76 \times 12}{.9 \times 60 (20 - 3/2)}$

$= 5.26 in^2$

$w_u = 1.2DL + 1.6LL$

$= 1.2 \times 2 + 1.6 \times 2.3$

$= 6.08 \ K/ft.$

$M = \dfrac{w_u l^2}{8}$

$= \dfrac{6.08 \times 24^2}{8}$

$= 437.76 \ K\text{-}ft.$

check the assumed value for a,

$a = \dfrac{A_s f_y}{.85 f'_c b} = \dfrac{5.26 \times 60}{.85 \times 3 \times 47} = 3.30 \text{ inch.}$

a) t ⇒ T-beam analysis is required.

$\therefore A_{sf} = \dfrac{.85 f'_c (b - b_w) t}{f_y}$

$= \dfrac{.85 \times 3 \times (47 - 11) \times 3}{60} = 4.59 \ in^2$

$\therefore M_{uf} = \phi A_{sf} f_y (d - t/2)$

$= .9 \times 4.59 \times 60 (20 - 3/2)$

$= 4590 \ K\text{-}in = 382.5 \ K\text{-}ft.$

$M_{uw} = 437.76 - 382.5 = 55.26 \ K\text{-}ft.$

<u>Assume</u>: $a = 4$ inch.

$A_s - A_{sf} = \dfrac{M_{uw}}{\phi f_y (d - a/2)} = \dfrac{55.26 \times 12}{.9 \times 60 (20 - 4/2)}$

$= 0.68 \ in^2$

<u>check</u>:

$a = \dfrac{(A_s - A_{sf}) f_y}{.85 f'_c b_w} = \dfrac{.68 \times 60}{.85 \times 3 \times 11} = 1.45''$

$\therefore A_s - A_{sf} = \dfrac{55.26 \times 12}{.9 \times 60 \times (20 - \frac{1.45}{2})}$

$= 0.68 \ in^2$

$$\therefore a = \frac{(A_s - A_{sf}) f_y}{.85 f'_c b_w} = \frac{.68 \times 60}{.85 \times 3 \times 11} = 1.45''$$ ok.

$$\therefore A_s = A_{sf} + (A_s - A_{sf})$$
$$= 4.59 + 0.68$$
$$= 5.27 \text{ in}^2$$

Ans.

* A floor slab 3" thick by RCC beam 5' on centers which act as a T-beam. The beam is simply supported with 14 ft span. They have web width 10" with effective depth 20". The tensile reinforced bar consists of 6-#10 bar in two rows. $f_y = 40$ ksi, $f'_c = 3$ ksi. Check whether it is T-Beam or not?

Soln: Effective flange width:

① $b = 16t + b_w = 16 \times 3 + 10 = 58''$

② $b = \frac{L}{4} = \frac{14 \times 12}{4} = 42''$

③ $b = 5 \text{ ft} = 60''$

$\therefore b = 42''$

$A_s = 6 \times 1.27$
$= 7.62 \text{ in}^2$

$$a = \frac{A_s f_y}{.85 f'_c b} = \frac{7.62 \times 40}{.85 \times 3 \times 42} = 2.85 \text{ inch}$$

$$\therefore c = \frac{a}{\beta_1} = \frac{2.85}{.85} = 3.35''$$

$\because c > t \rightarrow$ it is a T-beam.

Note: If $c \leq t \rightarrow$ it is modified rectangular beam in which the NA are situated in the flange.

Shear & Diagonal Tension in Beam

Stirrup: It is the reinforcement used to resist shear and diagonal tension stresses in a concrete structural member. A steel bar bent into a 'U' or box shape and installed perpendicular to the longitudinal reinforcement and properly anchored is called stirrup.

What is diagonal tension & when it creates?

Ans: For the applied load on RCC beam, it develops compression stress above NA and tensile stress below NA. Thus the two types of stress acting on a beam which causes diagonal crack. These diagonal cracks cause diagonal stress which is termed as diagonal tension.

Because of -

① Under reinforcement used in external applied load.

② Don't proper use of web reinforcement.

purposes of shear/web reinforcement:

① It increases the member strength against diagonal tension failure by transferring shear force directly.

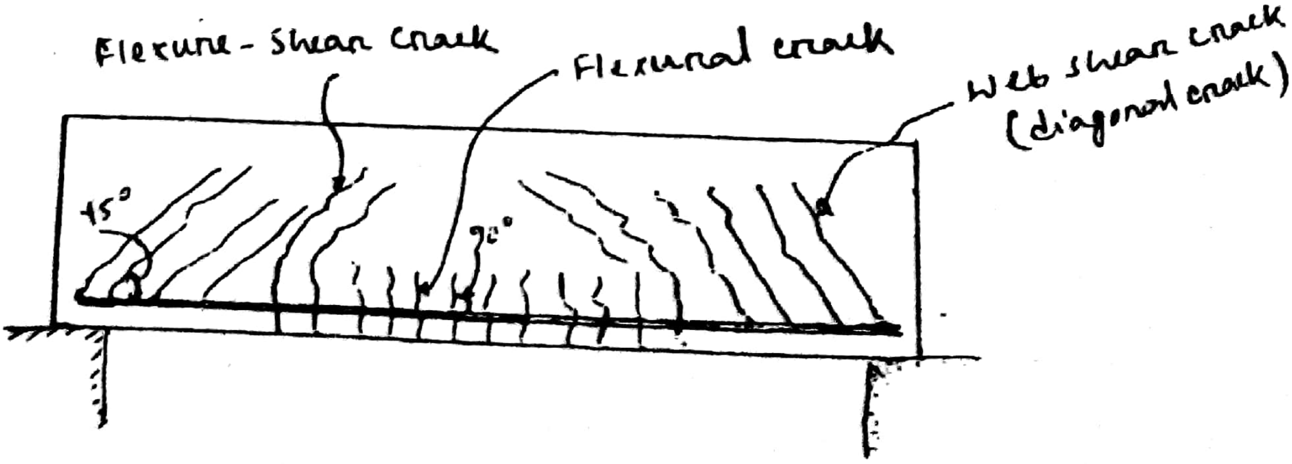
② It improves the member ductility.

③ It holds the main reinforcement in proper position.

④ It helps to maintain the intensity of compression zone.

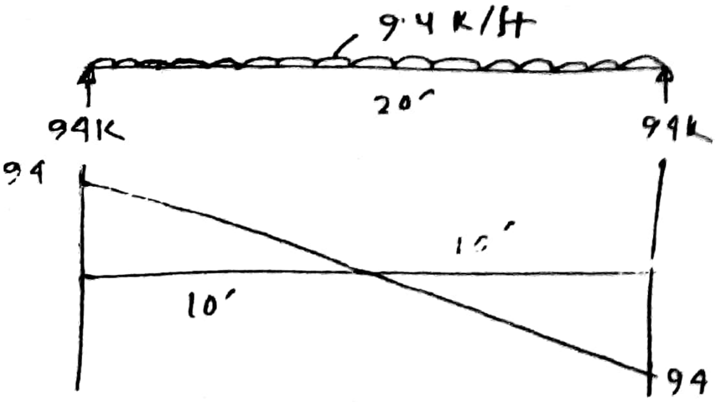
Draw the flexural and diagonal crack in a beam.

Ans:



* A simply supported rectangular beam 16" wide having an effective depth of 22" carries a total factored load of 9.4 k/ft on a 20' clear span. It is reinforced with 7.62 in² of tensile steel, which continues uninterrupted into the supports. $f'_c = 4$ ksi, $f_y = 60$ ksi. Design the web reinforcement.

Soln:



Critical shear: Critical shear develops at a distance $d = 22" = 1.83'$ from the face of the support.

$$V_u = \frac{94}{10}(10 - 1.83) = 76.8\ K$$

Shear capacity of concrete:

$$\phi V_c = \phi\, 2\lambda \sqrt{f'_c}\, b_w d$$

$$= .75 \times 2 \times 1 \times \sqrt{4000} \times 16 \times 22$$

$$= 33.4\ K$$

$\phi = 0.75$
$b_w = 16"$
$d = 22"$
$\lambda = 1 \rightarrow$ normal wt concrete
$= .75 \rightarrow$ light wt concrete.

$V_u > \phi V_c$; so. shear reinforcement is required.

From ACI code shear reinforcement is provided for $\frac{\phi V_c}{2} = 16.7$ K that acts at a distance 8.22' from the face of the support.

Spacing:

$$S = \frac{\phi A_v f_y d}{V_u - \phi V_c}$$

$$\left[\text{Excess shear} \quad \phi V_s = V_u - \phi V_c\right]$$

$S_{max} = d/2 = 11"$

$S_{min} = 4"$

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① Location at which max^m spacing can be used.

$$s = \frac{\phi A_v f_y d}{V_u - \phi V_c} \qquad [A_v = 2 \times .11]$$

$$\Rightarrow V_u = \frac{.75 \times 2 \times .11 \times 60 \times 22}{11} + 33.4 = 53.2\,k$$

It applies at a distance $\left(10 - \frac{10 \times 53.2}{94}\right) = 4.35\,ft$ from the support.

② From the support to a distance $d = 1.83'$

$$S_1 = \frac{\phi A_v f_y d}{V_u - \phi V_c} = \;'' > S_{min}$$

$V_u = 76.8$

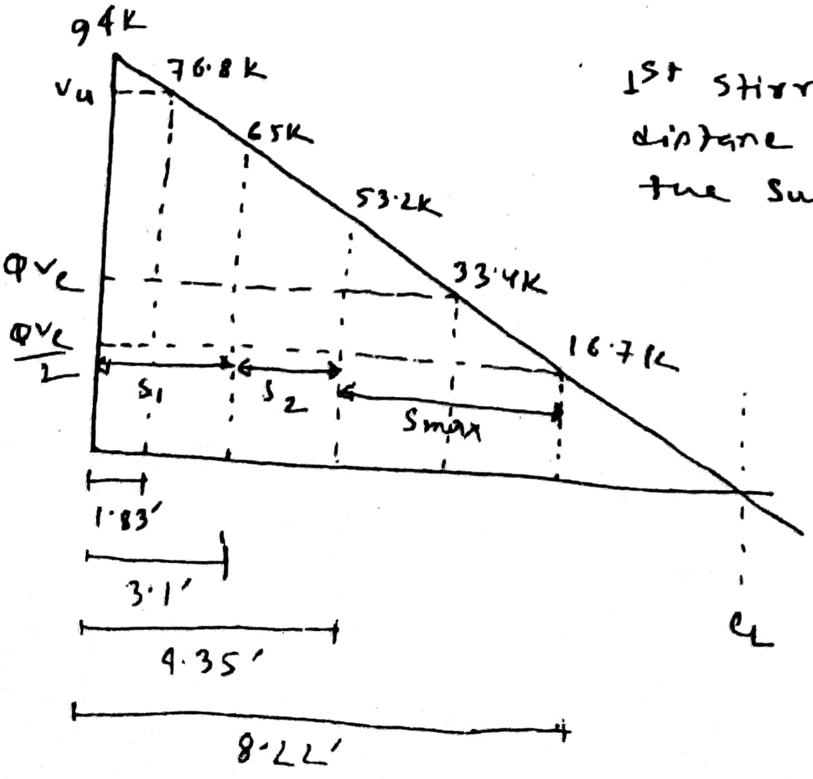
③ Between S_1 & S_{max}

$$\text{Avg. shear} = \frac{76.8 + 53.2}{2} = 65 \text{ kips.}$$

It applies $\left(10 - \frac{65 \times 10}{94}\right) = 3.1$ ft from support.

$$S_2 = \frac{\phi A_v f_y d}{V_u - \phi V_c} = \frac{.75 \times 2 \times .11 \times 60 \times 22}{65 - 33.4}$$

$$= 7''$$



1st stirrup place at a distance $d = 1.83'$ from the support.

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Note: $V_u < \phi V_c$ দেখা হয় তাহলে theoretically shear reinforcement লাগবে না, তবুও minimum shear reinforcement দিতে হবে।

Bond, Anchorage & Development Length

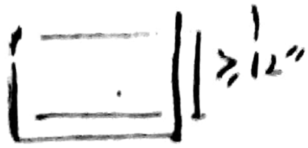
* **Development Length:** The development length is defined as that length of embedment necessary to develop the full tensile strength of the bar, controlled by either pullout or splitting.

Basic Equation:

$$l_d = \left(\frac{3}{40} \frac{f_y}{\lambda \sqrt{f'_c}} \frac{\psi_t \psi_e \psi_s}{\frac{c + K_{tr}}{d_b}} \right) d_b$$

where,

ψ_t = location factor (1.3/1.0)



ψ_e = coating factor

= 1.0 for no coating

= 1.2 for epoxy coating

= 1.5 for epoxy coating with clear cover $\leq 3d_b$

ψ_s = size factor

= 1 for greater or equal #7 bar

= 0.8 for less than #7 bar

c = spacing or cover dimension

K_{tr} = transverse reinforcement index.

$$= \frac{40 A_{tr}}{sn} \leq 2.5$$

d_b = Dia of bar.

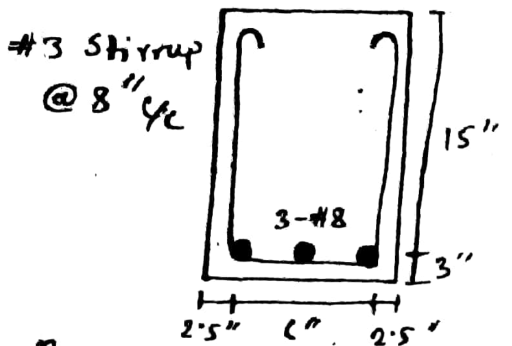
s = Max^m spacing of transverse reinforcement.

n = Nos. of bar.

* Determine the development length required for the #8 uncoated bottom bars shown in figure.

(a) $K_{tr} = 0$

(b) use computed value of K_{tr}



$f_y = 60\ ksi$

$f'_c = 3\ ksi$

Sol^n:

$\psi_t = 1$ for bottom bars.

$\psi_e = 1$ for uncoated bars.

$\psi_s = 1$ for #8 bars.

$\lambda = 1$ for normal wt concrete.

Value of c:

① side cover = 2.5"

② one-half of c/c spacing of bars = $3/2 = 1.5$"

so, $c = 1.5$"

(a) $$\frac{c + K_{tr}}{d_b} = \frac{1.5 + 0}{1} = 1.50 < 2.50$$ ok

$$l_d = \frac{3}{40} \frac{f_y}{\lambda \sqrt{f'_c}} \frac{\psi_t \psi_e \psi_s}{\frac{c + K_{tr}}{d_b}} \times d_b$$

$$= \frac{3}{40} \times \frac{60,000}{1\sqrt{3000}} \times \frac{1 \times 1 \times 1}{1.5} \times 1$$

$= 55$ inch.

(b) $K_{tr} = \frac{40 A_{tr}}{sn} = \frac{40\pi(2\times .11)}{8\times 3} = 0.367$ in

$\frac{c + K_{tr}}{d_b} = \frac{1.5 + .367}{1.0} = 1.867 < 2.5$

ok

$l_d = \frac{3}{40}\frac{f_y}{\lambda\sqrt{f'_c}}\frac{\psi_t\psi_e\psi_s}{\frac{c+K_{tr}}{d_b}} d_b$

$= 44$ in

Ans.

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Draw the reinforcement detailing of one way & two way slab.

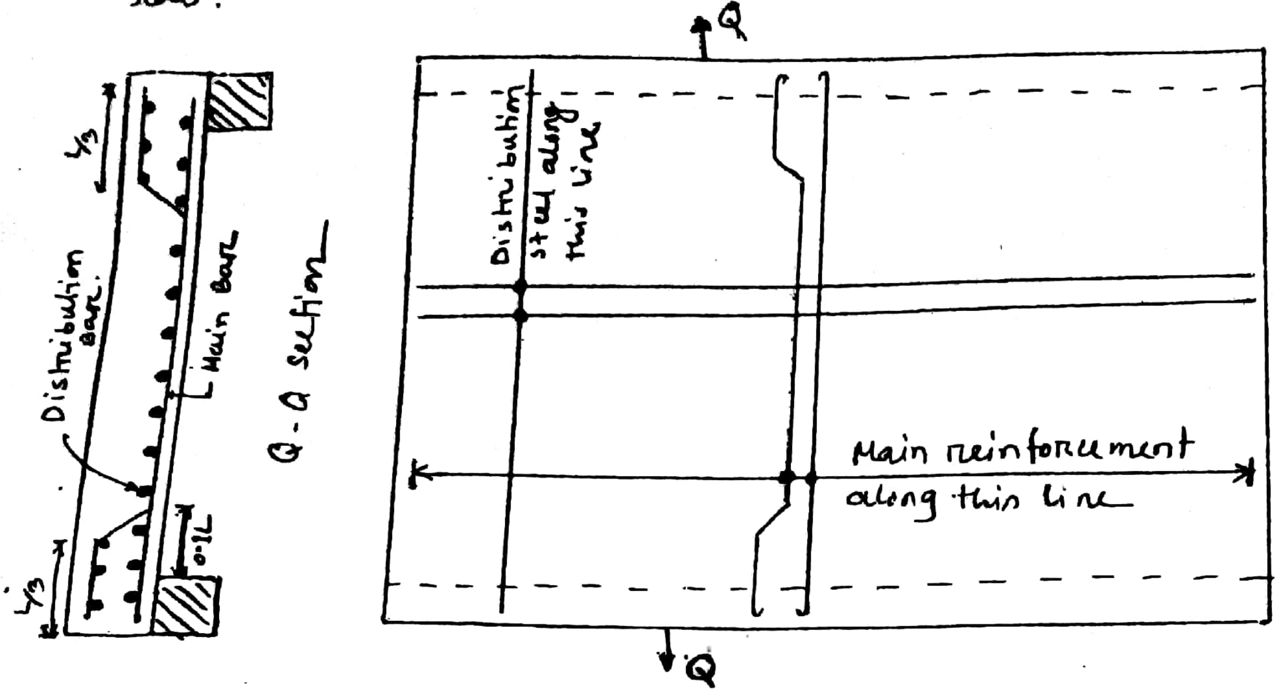
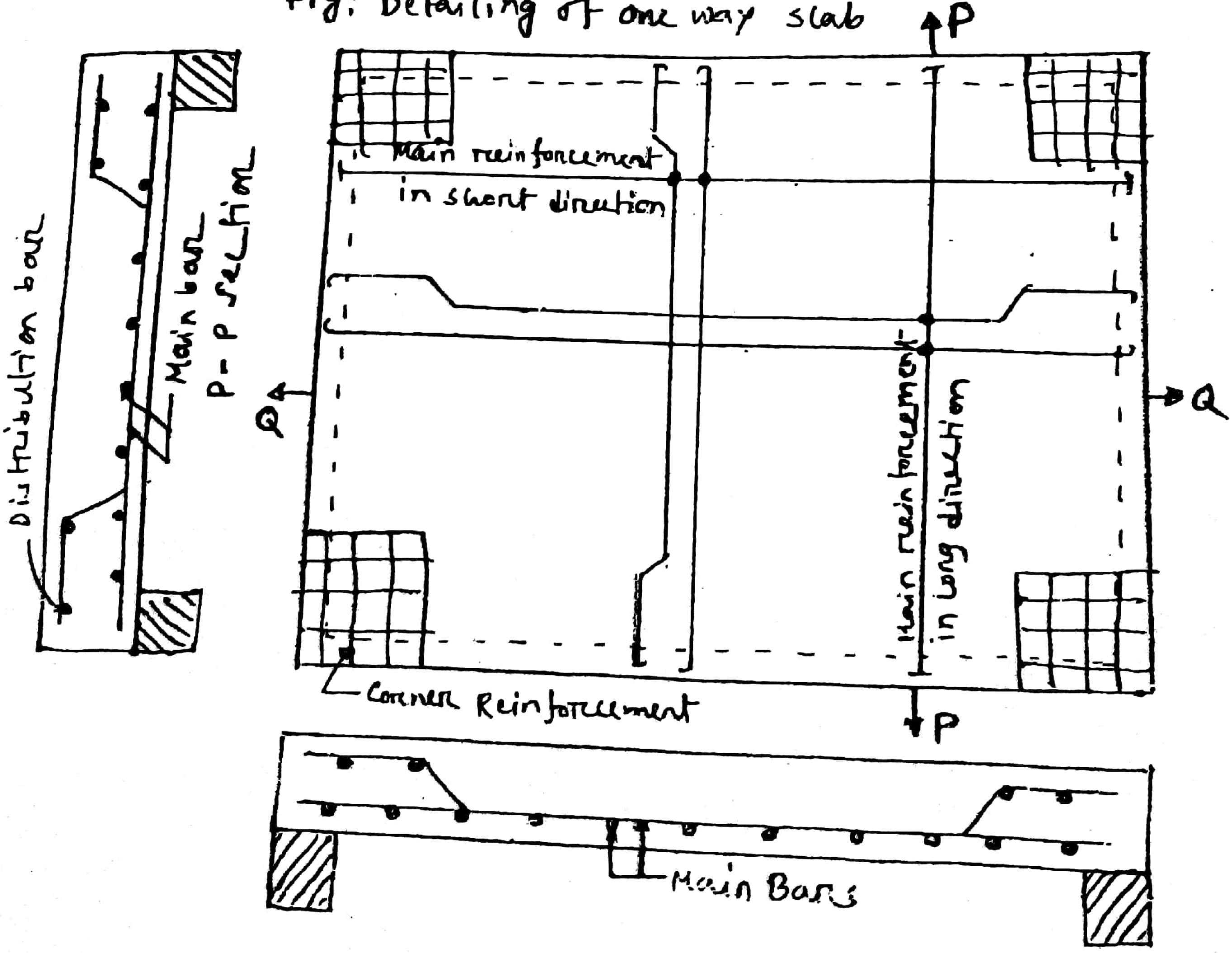


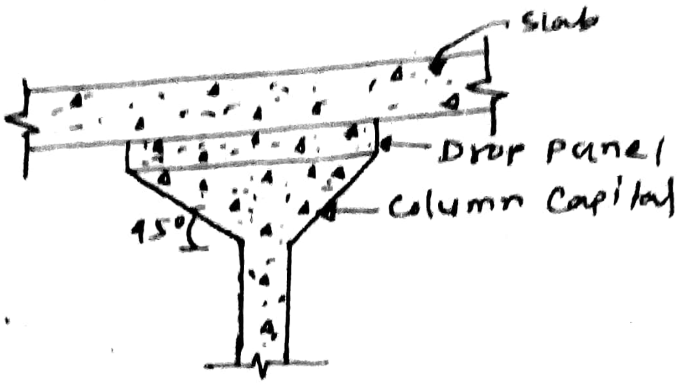
Fig: Detailing of one way slab



Q-Q section

Write down the component of flat slab.

Ans:

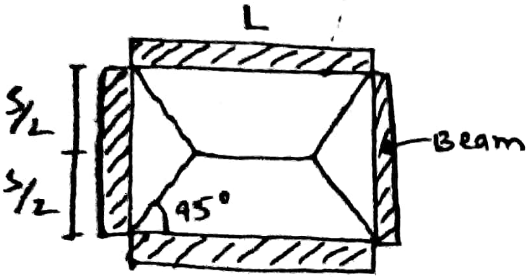


Slab Thickness: (Minimum)

D-Chain-16

Name	WSD	USD
Simply supported	L/25	L/20
One end continuous	L/30	L/24
Both end continuous	L/35	L/28
Cantilever	L/12	L/10

Load distribution of slab on beam.



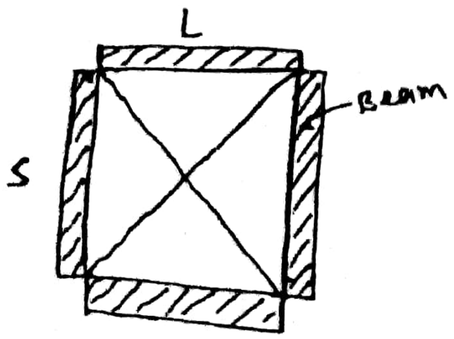
(i) rectangular slab.

① Load transferred in short direction per ft of beam

$$= \frac{wS}{3}$$

② Load transferred in long direction per ft of beam

$$= \frac{wS}{3}\left(\frac{3-m^2}{2}\right)$$



S = c/c length in short direction

w = load including self wt of slab

$m = S/L$

(ii) Square slab

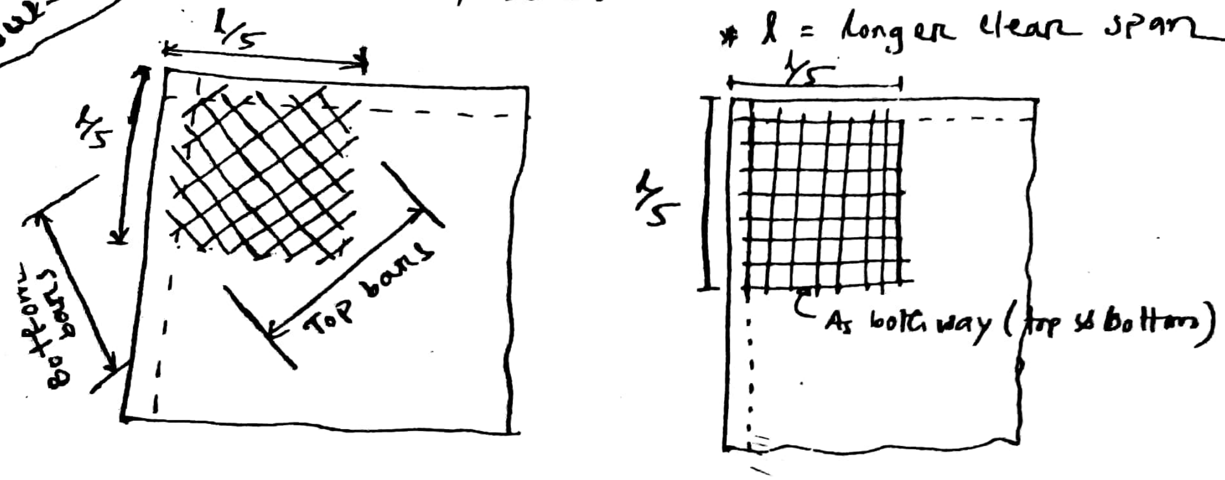
What is corner reinforcement? why it is used?

Ans: A special reinforcement shall be provided at exterior corners in both bottom and top of the slab, for a distance in each direction from the corner equal to one-fifth the larger span of the corner panel. It is provided due to -

① resist- diagonal crack
② resist- twisting moment at exterior corner of a two way slab.

Raise-14

* l = longer clear span



OPtion-I   OPtion-2

Temperature & shrinkage reinforcement:

① For 40 or 50 grade bar → 0.002 bt
② For 60 grade bar → 0.001857
③ more than 60 grade → $\frac{.0018 \times 60{,}000}{f_y}$ bt.

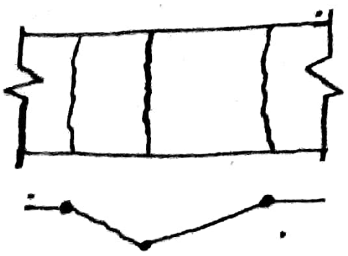
Two way slab thickness:

Minimum trail thickness, $t = \frac{\text{perimeter}}{180} = \frac{2(l_a+l_b)\times 12}{180}$

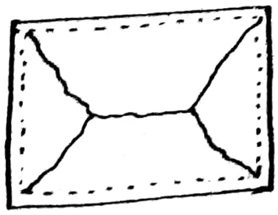
where, l_a, l_b → clear span on either two direction

Design of slab: Lecture note

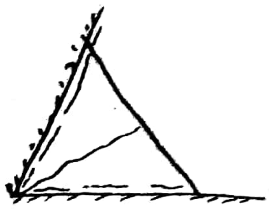
Typical yield line patterns:



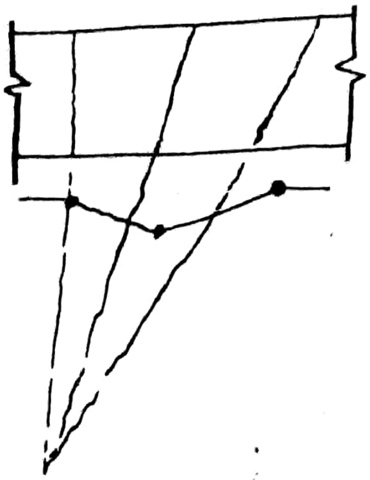
a) Slab continuous over parallel supports.



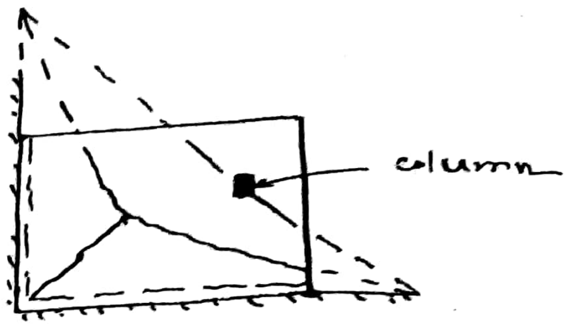
(d) Two-way slab on simple supports



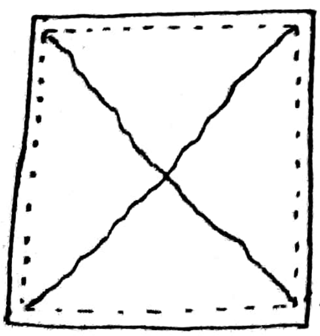
e) Fixed supports two sides.



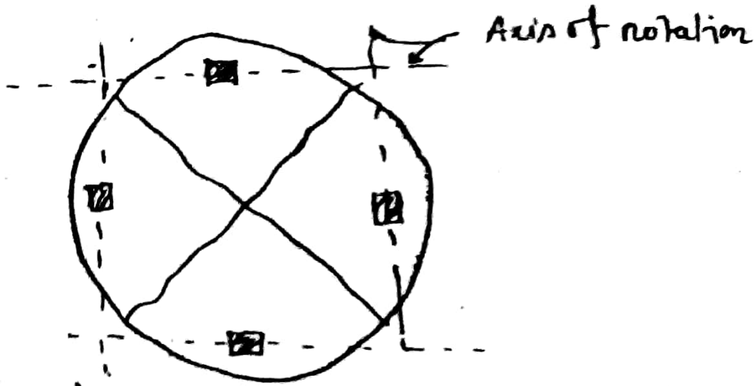
b) Continuous slab on non parallel supports.



f) Fixed supports two sides



(c) simple supports all sides.



g) Four columns.

h) Fixed supports on three sides

* Determine the spacing required for the temperature & shrinkage reinforcement in a one way slab of thickness $t = 6''$. Consider #3 deformed bar with $f_y = 60$ ksi, $f'_c = 3$ ksi. Follow the ACI code specification.

<u>Soln:</u>

$$A_s = 0.0018bt$$
$$= 0.0018 \times 12 \times 6$$
$$= 0.13 \, in^2/ft$$

spacing for # 3 bar

$$s = \frac{0.11}{0.13} \times 12 \simeq 10'' \, c/c$$

<u>Ans.</u>

"Column"

Longitudinal steel / Rebar ratio:

ACI Code → $\frac{A_{st}}{A_g} = 1\% \sim 8\%$
(min^m) (max^m)

BNBC code → $\frac{A_{st}}{A_g} = 1\% \sim 6\%$
(min^m) (max^m)

Why smaller reduction factor is used in a column compared to beam?

Ans: Because of -

i) Beam failure would normally effect on only a load region where a column failure would result in collapse of the entire structure.

Why load capacity of spiral column is greater than tied column?

Ans:

① Tied column under loaded condition, the concrete failure occurs due to crushing & shearing. But for spiral column under loaded condition, longitudinal steel and concrete are prevented by concrete core.

② Longitudinal steel buckling outward in between ties for tied column. But longitudinal steel buckling are prevented by concrete core.

# Column Name	Minimum bar No.	Multiple of
Square column	4	4
Rectangular col^m	4	2
Circular (tied)	4	1
Circular (spiral)	6	1
Triangular col^m	3	3

Specification for tie & spiral reinforcement:

① Tie specification:

i) spacing, $s = 16 \times d_{main\ bar}$

ii) spacing, $s = 48 \times d_{tie\ bar}$

iii) spacing, s = least column dimension

smallest value is acceptable

② Spiral specification:

① Minimum spiral ratio, $\rho_{s(min)} = 0.45 \left(\frac{A_g}{A_c} - 1\right) \frac{f'_c}{f_y}$

where, A_c = Area of core.

② pitch, $g = \frac{1}{6} D_c \Rightarrow 1 \leq g \leq 3$

③ spiral ratio, $\rho_s = \frac{4 a_s}{g D_c}$ ⇒ should be greater than $\rho_{s(min)}$

where, a_s = Area of spiral bars.

Function of tie bar:

- hold the main bar at right position
- decrease the development length.
- resist the buckling effect.

Interaction Diagram: It is defined as the failure load and failure moment for a given column for full range of eccentricities from zero to infinity.

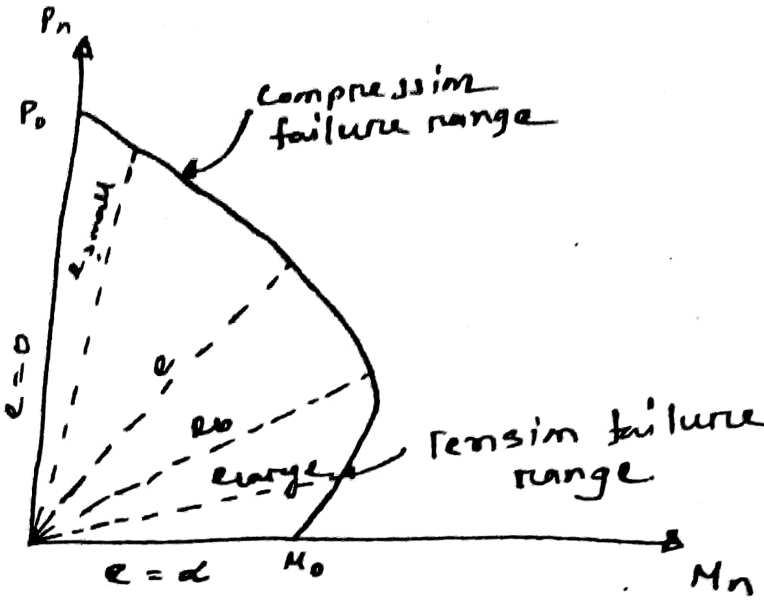


Fig: Interaction diagram for nominal column strength in combined bending & axial load.

- Any radial line represents a particular eccentricity. $\frac{M_n}{}$

- Larger eccentricities produce failure governed by concrete compression.

- Smaller eccentricities will produce failure governed by steel tension.

Column Capacity: (USD)

① **Tied column:**

$$P_u = \alpha\varphi\left[0.85 f'_c (A_g - A_{st}) + f_y A_{st}\right]$$

where,

$\alpha = 0.80$ | For zero eccentricity, $\alpha = 1$

$\varphi = 0.65$ | Nomial capacity চাইলে $(\alpha\varphi)$ বাদ

② **Spiral column:**

$$P_u = \alpha\varphi\left[0.85 f'_c (A_g - A_{st}) + f_y A_{st}\right]$$

where,

$\alpha = 0.85$

$\varphi = 0.75$

* If live load is 400k and dead load is 500k as well as $f'_c = 4$ ksi, $f_y = 60$ ksi. What is the gross area of tied column.

Soln:

$$P_u = \alpha\varphi\left[.85 f'_c (A_g - A_{st}) + f_y A_{st}\right]$$

Let, $\rho_g = 0.03 \Rightarrow A_{st} = 0.03 A_g$

$\therefore 1.2 \times 500 + 1.6 \times 400 = .80 \times .65\left[.85 \times 4(A_g - .03A_g) + 60 \times .03 A_g\right]$

$\Rightarrow A_g = 467.75 \text{ in}^2$

$\therefore$ Column size $= 22'' \times 22'' = 484 \text{ in}^2$

ok

* A column with the cross-section shown below with, $f'_c = 4$ ksi & $f_y = 60$ ksi subjected to a concentrated axial load. The column section (15"x15") reinforced with 8-#8 bars. Cal. the ultimate load carrying capacity of the column.

Sol^n: $A_{st} = 8 \times .79 = 6.32 in^2$, $A_g = 15 \times 15 = 225 in^2$.

$$\therefore \rho_g = \frac{A_{st}}{A_g} = \frac{6.32}{225} \times 100 = 2.81\%$$ ok

$$\therefore P_u = \alpha\varphi\,[.85 f'_c\,(A_g - A_{st}) + f_y A_{st}]$$

$$= .80 \times .65 \times [.85 \times 4 \times (225 - 6.32) + 60 \times 6.32]$$

$$= 583.81 \text{ Kips}$$

Ans

* Compute steel ratio/concrete ratio if steel uses in the column is 1% of total size of column Area & steel ratio $\gamma = 10$.

Sol^n: Here, $A_s = 1\%$ of $A_g = 0.01 A_g$

$\gamma = 10$

RRI-14

$$\Rightarrow \frac{f_s}{f_c} = 10 \Rightarrow \frac{\frac{P_s}{A_s}}{\frac{P_c}{A_c}} = 10 \Rightarrow \frac{P_s}{A_s} \times \frac{A_c}{P_c} = 10 \Rightarrow \frac{P_s}{P_c} \times \frac{A_g - A_s}{A_s} = 10$$

$$\Rightarrow \frac{P_s}{P_c} \times \frac{A_g - 0.01 A_g}{.01 A_g} = 10 \Rightarrow \frac{P_s}{P_c} = 0.1010 = 10.1\%$$

Ans.

* Find the design ultimate axial stress of the column with zero eccentricity. Steel Area = 2%., Column size 12"x12". $f_y = 60$ ksi, $f'_c = 3.5$ ksi.

Sol^n:

$$A_g = 12 \times 12 = 144 in^2, \quad A_{st} = \frac{2}{100} \times 144 = 2.88 in^2$$

RL-16 $\therefore P_u = \alpha\varphi\,[.85 f'_c\,(A_g - A_{st}) + f_y A_{st}]$ ($\alpha = 1$ for zero eccentricity)

$$= 1.0 \times .65 \times [.85 \times 3.5\,(144 - 2.88) + 60 \times 2.88]$$

$$= 386.17 \text{ Kips}$$

$$\therefore \text{stress} = \frac{386.17}{144} = 2.68 \text{ ksi}$$

Ans.

Design of tied column (USD):

Design a square tied column to carry axial service loads of 320k dead load and 190 k live load. Use $f'_c = 4$ ksi, $f_y = 60$ ksi.

Soln: Assume, steel ratio, $\rho_g = 0.03 \Rightarrow A_{st} = 0.03 A_g$.

$$P_u = 1.2 \times 320 + 1.6 \times 190 = 688 \text{ kips.}$$

For tied column,

$$P_u = \alpha \phi \left[.85 f'_c (A_g - A_{st}) + f_y A_{st} \right]$$

$$\Rightarrow 688 = 0.80 \times 0.65 \left[.85 \times 4 (A_g - .03 A_g) + 60 \times .03 A_g \right]$$

$$\Rightarrow A_g = 259.53 \text{ in}^2$$

$\therefore$ side of square column $= \sqrt{259.53}$

$= 16.11 \simeq 17$ in

$\therefore$ Column size $= 17'' \times 17''$; $A_g = 289$ in^2

Load carried by concrete,

$$P_{uc} = 0.8 \times 0.65 \times .85 \times 4 \times (289 - .03 \times 289)$$

$$= 495.6 \text{ kips.}$$

Load carried by steel,

$$P_{us} = P_u - P_{uc} = 192.38 \text{ kips.}$$

$$\therefore P_{us} = 0.8 \times 0.65 \times 60 \times A_{st}$$

$$\Rightarrow 192.38 = 0.8 \times 0.65 \times 60 \times A_{st}$$

$$\Rightarrow A_{st} = 6.16 \text{ in}^2$$

Use #8 bar. No. of bar $= \dfrac{6.16}{.79} \simeq 8$ Nos.

$$\therefore \rho_g = \frac{A_{st}}{A_g} = \frac{8 \times .79}{289} = 0.0219$$

(OK)

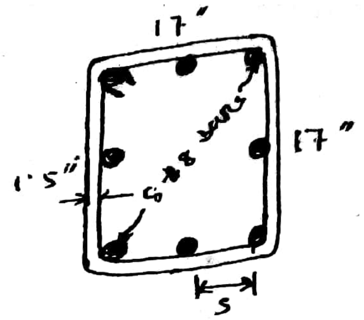
Design of ties:

use #4 bars

1. $16\, d_{LB} = 18.89''$

2. $48\, d_{TB} = 24''$

3. $a_{min} = 17''$



$s = 6.25'' > 1.5\, d_b$

OK

use 12mm tie bar @ 16" c/c vertically.

Design of spiral column: (USD)

* Design a circular spiral-reinforced column for a concentric allowable working load of 480 kips with $f'_c = 4$ ksi & $f_y = 60$ ksi.

Soln: Assume, $\rho_g = 0.02 \Rightarrow A_{st} = 0.02\, A_g$.

$$P_u = \alpha \phi \left[.85 f'_c (A_g - A_{st}) + f_y A_{st} \right]$$

$$\Rightarrow 480 = 0.85 \times 0.75 \left[.85 \times 4 (A_g - .02 A_g) + 60 \times .02 A_g \right]$$

$$\Rightarrow A_g = 166.14 \text{ in}^2$$

$$\Rightarrow \frac{\pi}{4} D^2 = 166.14 \quad \Rightarrow D \simeq 15''$$

$$\therefore A_g = \frac{\pi}{4} \times 15^2 = 176.72 \text{ in}^2$$

Load carried by concrete.

$$P_{uc} = .85 \times .75 \times .85 \times 4 \, (176.72 - .02 \times 176.72)$$

$$= 375.38 \text{ kips.}$$

Load carried by steel.

$$P_{us} = P_u - P_{uc} = 480 - 375.38 = 104.62 \text{ kips.}$$

$$\therefore P_{us} = 0.85 \times .75 \times 60 \times A_{st}$$

$$\Rightarrow A_{st} = \frac{104.62}{38.25} = 2.66 \text{ in}^2$$

provide 4 - #8 bars. $A_s = 4 \times .79 = 3.16 \, in^2$

$$\rho_g = \frac{A_{st}}{A_g} = \frac{3.16}{176.72} = 0.018$$

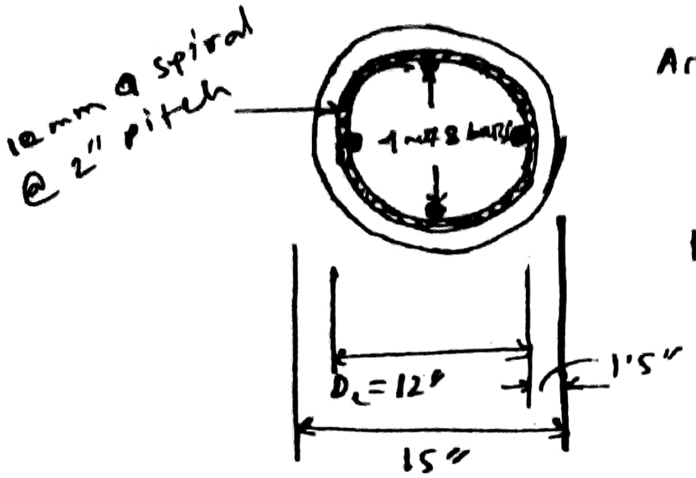
ok

clear spacing between adjacent bars.

$$= \frac{\pi \times 12 - 4 \times 1}{4} = 8.42'' > 1.5 d_b$$

ok

Design of spiral:



Area of core, $A_c = \frac{\pi}{4} \times 12^2$

$= 113.1 \, in^2$

pitch, $g = \frac{1}{6} D_c \quad (1 \le g \le 3)$

$= 2''$

ok

Minimum Spiral Ratio, $\rho_{s(min)} = .45 \left(\frac{A_g}{A_c} - 1 \right) \frac{f'_c}{f_y}$

$= 0.0169$

~~spriral ratio~~. spiral ratio (use #3 bar)

$$\rho_s = \frac{4 a_s}{g D_c} = \frac{4 \times 0.11}{2 \times 12} = 0.0183 > \rho_{s(min)}$$

ok

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* A column consists of 12 no #9 bars. Calculate the size, spacing and draw them.

Soln: Consider a tied column.

$h = 2\times1.5 + 2\times.4 + 5\times1.125 + 4\times1.6875$

$= 16.18'' \simeq 16.5''$

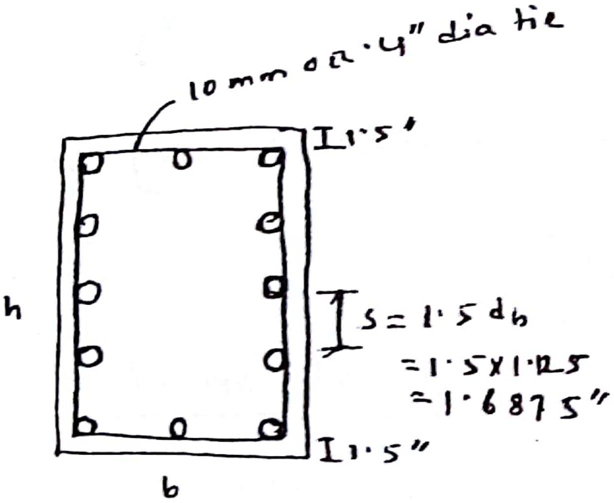
$b = 2\times1.5 + 2\times.4 + 3\times1.125 + 2\times1.6875$

$= 10.5''$

Spacing, $s = 1.6875''$

$\therefore$ size $= 10.5'' \times 16.5''$

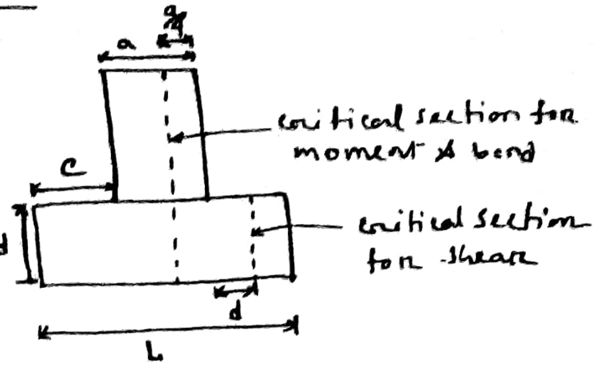
Ans.



"Footing & Foundation"

Critical section for different types of footing:

① Brick (Masonry) wall footing:



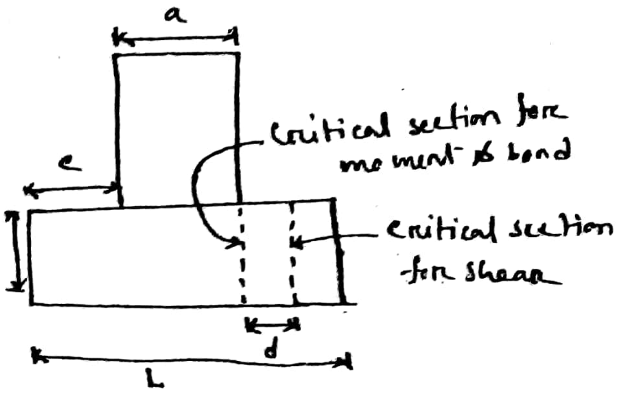
a) Area, $A = (L \times 1)\ m^2$

b) Moment, $M = \dfrac{w(2L-a)^2}{32}$

c) Shear force at critical shear section, $V_v = (c-d)w$

d) shear force at critical moment & bond section,
$V_b = (c + a/4)w$

② Concrete wall footing:



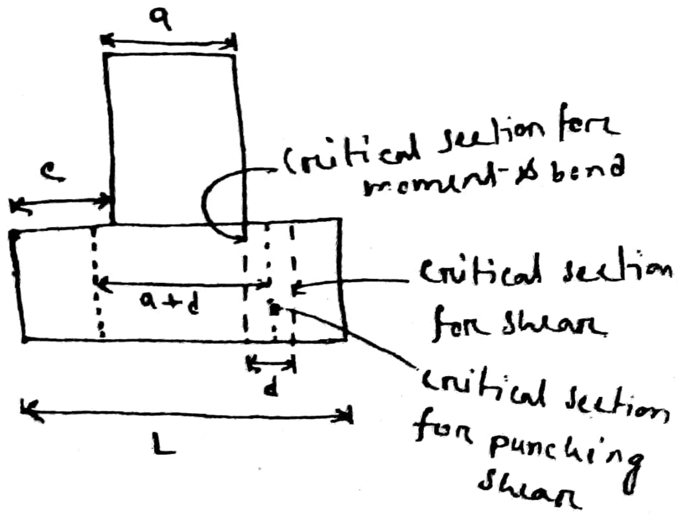
a) Area, $A = (L \times 1)\ m^2$

b) Moment, $M = \dfrac{w(L-a)^2}{8}$

c) Shear force at critical shear section, $V_v = (c-d)W$

d) shear force at critical moment & bond section,
$V_b = cw$

③ Independent (RCC) column footing:



a) Area, $A = (L \times L)\ m^2$

b) Moment, $M = \dfrac{WLc^2}{2}$; $c = \dfrac{L-a}{2}$

c) shear force at critical shear section, $V_v = (c-d)LW$; where allowable stress, $v_c = 1.1\sqrt{f'_c}$ psi

d) Shear force at critical moment & bond section, $V_b = cLW$; where allowable stress, $v_c = 1.1\sqrt{f'_c}$ psi

e) Shear force at critical punching shear section,
$V_c = [L^2 - (a+d)^2]W$; where allowable stress, $v_c = 2\sqrt{f'_c}$ psi

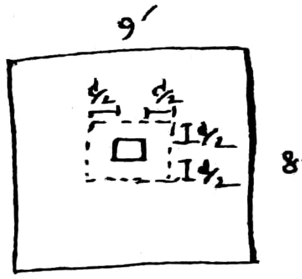
f) punching Area, $A_c = 4(a+d) \times d$

* A 18"x18" RCC column made a footing size 8'x 9' will supports a total load of 23000 lb/ft. The bearing pressure of soil is 2 tsf. Determine footing depth. $f'_c = 3000\,psi$, $f_y = 40000\,psi$.

Solⁿ:

Shear force, $V = \left(9 \times 8 - \frac{(18+d)^2}{144}\right) * P_s$

$= \left\{72 - \frac{(18+d)^2}{144}\right\} * 4400$



soil pressure,

$P_s = 2\,t/ft^2$

$= 4400\,psf$.

Punching Area $= 4(a+d) * d$

$= 4(18+d) * d$

$\therefore$ Shear stress $= \dfrac{\left(72 - \frac{(18+d)^2}{144}\right) * 4400}{4(18+d)d}$

Again allowable stress,

$v_c = 2\sqrt{f'_c} = 109.54\,psi$

$\therefore \left\{\dfrac{\left(72 - \frac{(18+d)^2}{144}\right) * 4400}{4(18+d)d}\right\} = 109.54$

$\Rightarrow d = 17.74"$

Ans.

* A RCC footing size is 10'x10'. Determine the punching stress when depth 16.5" and column size (10"x10"). $f'_c = 4\,ksi$, $f_y = 60\,ksi$. → Soil pressure should be given.

Solⁿ:

Shear force, $V = \left\{10 \times 10 - \frac{(a+d)^2}{144}\right\} *$ soil pressure.

$= \left\{100 - \frac{(10+16.5)^2}{144}\right\} * w$

$= 95.12\,w$

Punching Area, $A_c = 4(a+d) * d$

$= 4(10+16.5) \times 16.5$

$= 1749\,in^2$

∴ punching stress, $= \frac{V}{A_o} = 0.0544W$ psi

Allowable stress $v_c = 2\sqrt{f'_c} = 2\sqrt{4000} = 126.49$

∴ $0.0544W = 126.49$

$\Rightarrow W = 2325.2$ psi.

∴ punching stress $= 0.0544 \times 2325.2$

$= 126.49$ psi Ans.

* A column 18" square with $f'_c = 4$ ksi reinforced with 8-#8 bars of $f_y = 60$ ksi, supports a dead load of 225K and a live load of 175 kips. The soil has a unit wt of 100 pcf. The allowable soil pressure $q_a = 5$ k/ft². Design a square footing with base 5' below grade.

Solⁿ: Avg. unit wt of concrete & soil $= \frac{100+150}{2} = 125$ pcf.

The pressure at 5' below grade $= 5 \times 125 = 625$ psf.

Effective soil pressure to carry the column load,

$q_e = (5000 - 625) = 4375$ psf.

∴ Required footing Area $A_{req} = \frac{(225+175) \times 10^3}{4375}$ (unfactored)

$= 91.5$ ft²

∴ Footing size $= 9'6'' \times 9'6'' = 90.3$ ft² > 91.5 ft² OK

Trail depth:

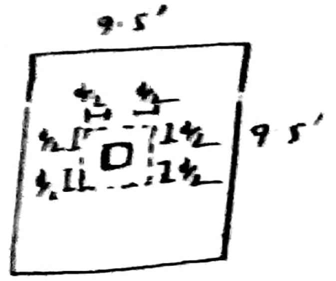
$90.3 \times h \times 150 = (225+175) \times 10^3 \times 6\%$

$\Rightarrow h = 1.72' \times 12$

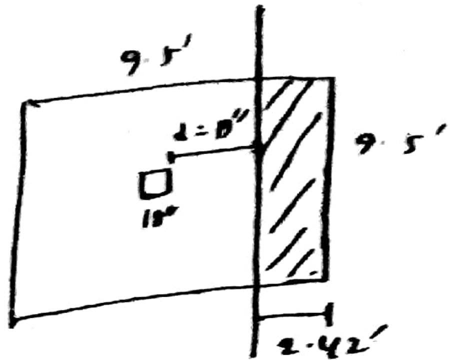
$= 22''$

(footing wt = 4~8% of colᵐ load)

∴ $d = 22 - 3 = 19''$



for punching



For Beam shear

check for punching shear:

$$q_u = \frac{(1.2 \times 225 + 1.6 \times 175) \times 10^3}{90.3}$$
$$= 6.1 \text{ ksf}$$

critical perimeter for punching shear, $b_o = 4(a+d)$
$= 4(18+19)$
$= 148$ inch.

Shear force acting on this perimeter, $V_u = 6.1\left\{9.5^2 - \left(\frac{18+19}{12}\right)^2\right\}$
$= 492$ kips.

Nominal shear strength,

$$\phi V_c = \phi\, 4 \lambda \sqrt{f'_c}\, b_o d$$
$$= (.75 \times 4 \times 1 \times \sqrt{4000} \times 148 \times 19)/1000$$
$$= 534 \text{ kips} > V_u$$

ok.

check for beam shear:

Shear force, $V_u = 6.1 \times (2.42 \times 9.5)$
$= 140$ kips.

Nominal shear strength,

$$\phi V_c = \phi\, 2 \lambda \sqrt{f'_c}\, b d$$
$$= \{.75 \times 2 \times 1 \times \sqrt{4000} \times (9.5 \times 12) \times 19\}/1000$$
$$= 205 \text{ kips} > V_u$$

ok

Steel Calculation:

Moment at the face of the column, $M = \frac{wLc^2}{2}$

$= \frac{6.1 \times 9.5 \times 4^2}{2} \times 12$

$= 5560$ in-kips.

$c = \frac{L-a}{2} = \frac{9.5 - \frac{18}{12}}{2} = 4'$

$A_s = \frac{M}{\phi f_y (d - a/2)}$ — ① $\quad a = \frac{A_s f_y}{.85 f'_c b}$ — ②

Trail between ① & ②

$A_s = 5.59 \text{ in}^2$

$A_{s(min)} = \frac{200}{f_y} bd$

$= \frac{200}{60000} (9.5 \times 12) \times 19$

$= 7.22 \text{ in}^2$

∴ provide 12 - #7 bars in each direction.

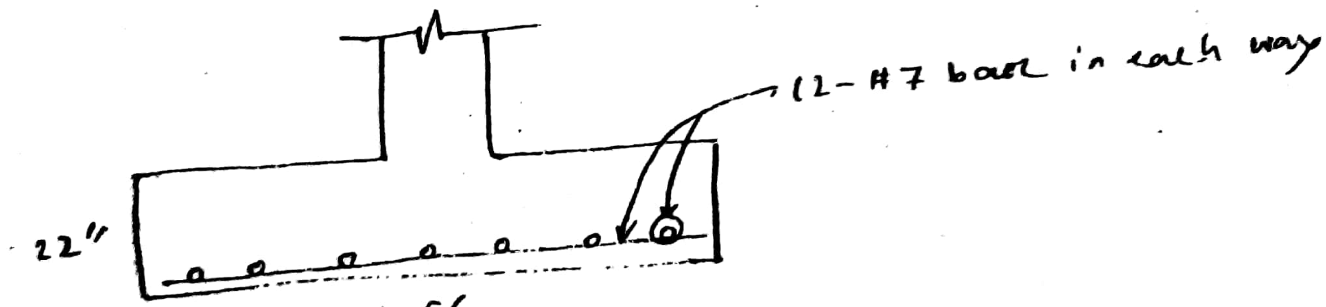


Fig: Detailing

* A 12-in thick concrete wall carries a dead load of 10 K/ft and live load of 12.5 K/ft. The bearing pressure of soil is 5 ksf at the level of the base of the footing which is 5 ft below the final ground surface. Determine footing depth. $f'_c = 3000$ psi, $f_y = 80000$ psi and density of soil is 120 lb/ft^3.

Solⁿ: Consider, 1 ft strip of footing.

Thickness of footing = 1~1.5 times of wall thickness

$= 12''$

Effective soil pressure, $q_e = 5 - (1 \times .15 + 4 \times .12)$

$= 4.37$ ksf.

Required footing Area, $A_{req} = \frac{(10+12.5)}{4.37}$

$= 5.2\ ft^2$ of length.

Check for beam shear:

$$q_u = \frac{1.2 * 10 + 1.6 * 12.5}{5.2} = 6.15 \text{ ksf}.$$

$V_u = 6.15 * (\frac{16.7}{12} \times 1)$

$= 8.56$ kips/ft.

$\frac{5.2 * 12}{2} - \frac{12}{2} - 8.5 = 16.7$

$d = 12 - 3'' - .5'' = 8.5''$

$\phi V_c = \phi\, 2 \lambda \sqrt{f'_c}\, bd$

$= (.75 \times 2 \times 1 \times \sqrt{3000} \times 12 \times 8.5)/1000$

$= 8.9$ kips/ft $> V_u$

ok

∴ Footing depth = 8.5″

Ans.